Climate Change Trends, Vulnerabilities, and Ecosystem Carbon,

Death Valley National Park, California

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Climate Trends for the Area within Park Boundaries

- **Temperature** Average annual temperature of the area within park boundaries increased at the statistically significant rate of 1.3 ± 0.5ºC per century in the period 1950-2010 (Table 1, Figure 1). The highest rate of temperature increase has been in summer, at 2.2 ± 0.8 ºC per century.
- **Temperature** Average annual temperature at the weather station at park headquarters increased at the statistically significant rate of 2.1 ± 0.3ºC per century in the period 1912-2015 (Figure 1).
- **Precipitation** Total annual precipitation of the area within park boundaries increased in the period 1950-2010 (Table 1, Figure 2), but the rate was not statistically significant.
- **Precipitation** Total annual precipitation at the weather station at park headquarters increased at the statistically significant rate of 59 ± 21% per century in the period 1912-2015 (Figure 2).
- **Spatial patterns** The highest historical rates of temperature increase have occurred at higher elevations in the Saline Range and other areas of the northwest section of the park, while the lowest rates of increase occurred in the already hot floor of Death Valley (Figure 3). The highest historical rates of precipitation increase have occurred on the floor of Death Valley (Figure 4).
- **Projections** If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project substantial warming and changes in precipitation (Table 1).
- **Projections** For projected average annual precipitation, the climate models do not agree, with the average of all models projecting an increase, but many individual models projecting decreases.
- **Aridity** Even if precipitation increases, temperature increases may overcome any cooling effects of increased precipitation, leading to increased evapotranspiration and overall aridity.
- **Extreme heat** Projections under the highest emissions scenario project an increase of 5 to 25 more days per year with a maximum temperature >35ºC (95ºF.) (Kunkel et al. 2013).
- **Extreme storms** Projections under the highest emissions scenario project an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 5-10 years (Walsh et al. 2014).

Future Vulnerabilities

- **Groundwater** Under hotter temperatures, decreased snowpack and increased evapotranspiration in mountain areas could reduce groundwater recharge for the Death Valley regional flow system, which depends almost entirely on recharge from the mountains (Meixner et al. 2016). This could increase the vulnerability to drying of seeps, springs, and the small wetlands areas that depend on them (Anderson et al. 2006).
- **Devil's Hole pupfish** The Devil's Hole pupfish (*Cyprinodon diabolis*), found in the world in only one small pool in Death Valley National Park, is vulnerable to a reduction of favorable spawning conditions from 74 to 57 days under high emissions (Hausner et al. 2014).
- **Invasive plant species** Under high emissions, the region would continue to be suitable habitat for invasive tamarisk trees (*Tamarix spp.*) and the range of the invasive yellow starthistle (*Centaurea solstitialis*) could expand in the region (Bradley et al. 2009).
- **Joshua trees** Under high emissions, warmer and drier conditions may eliminate the small area of suitable habitat for Joshua trees (*Yucca brevifolia*) in Death Valley National Park (Cole et al. 2011). Yet, the higher elevation land around Pinto Peak may become newly suitable.
- **Desert bighorn sheep** Research on desert bighorn sheep (*Ovis canadensis nelsoni*) in Death Valley National Park and Mojave National Preserve suggests that lower precipitation reduces forage quality and availability, forcing the sheep to expand the extent of their range (Oehler et al. 2009). Research on desert bighorn sheep (*Ovis canadensis nelsoni*) across southern California indicates that the increased temperature and aridity may contract the potential range of the species (Epps et al. 2004), with higher-elevation areas providing some refugia (Epps et al. 2006). Roads exacerbate the vulnerability of desert bighorns by reducing physical and genetic connectivity among isolated populations (Epps et al. 2005, 2007).
- **Desert tortoise** Research on the desert tortoise (*Gopherus agassizii*) in Joshua Tree National Park (Barrows 2011, Lovich et al. 2014), on Bureau of Land Management land in Kern County (Jennings and Berry 2015), and in Fort Irwin (Mack et al. 2015) and other Mojave Desert military bases (McCoy et al. 2011) indicates that the tortoise is vulnerable to increased mortality and range contractions under climate change due to heat stress (Barrows 2011, Mack et al. 2015), lack of water (Barrows 2011, Lovich et al. 2014), reduced forage (Jennings and Berry 2015), and increased predation (Lovich et al. 2014).
- **Woodrats** Paleoecological and recent data on Desert woodrats (*Neotoma lepida*) in Death Valley National Park (Murray and Smith 2012, Smith et al. 2014) and woodrats (*Neotoma spp.*) across the western U.S. (Smith et al. 2006) indicate that high temperatures reduce body

sizes and increase mortality.

- **Racetrack Playa rocks** The lack of rock movement from 2007 to 2014 may be due to reduction of strong winds and ice-forming cold temperatures, the latter of which is a factor consistent with climate change (Lorenz and Jackson 2014)

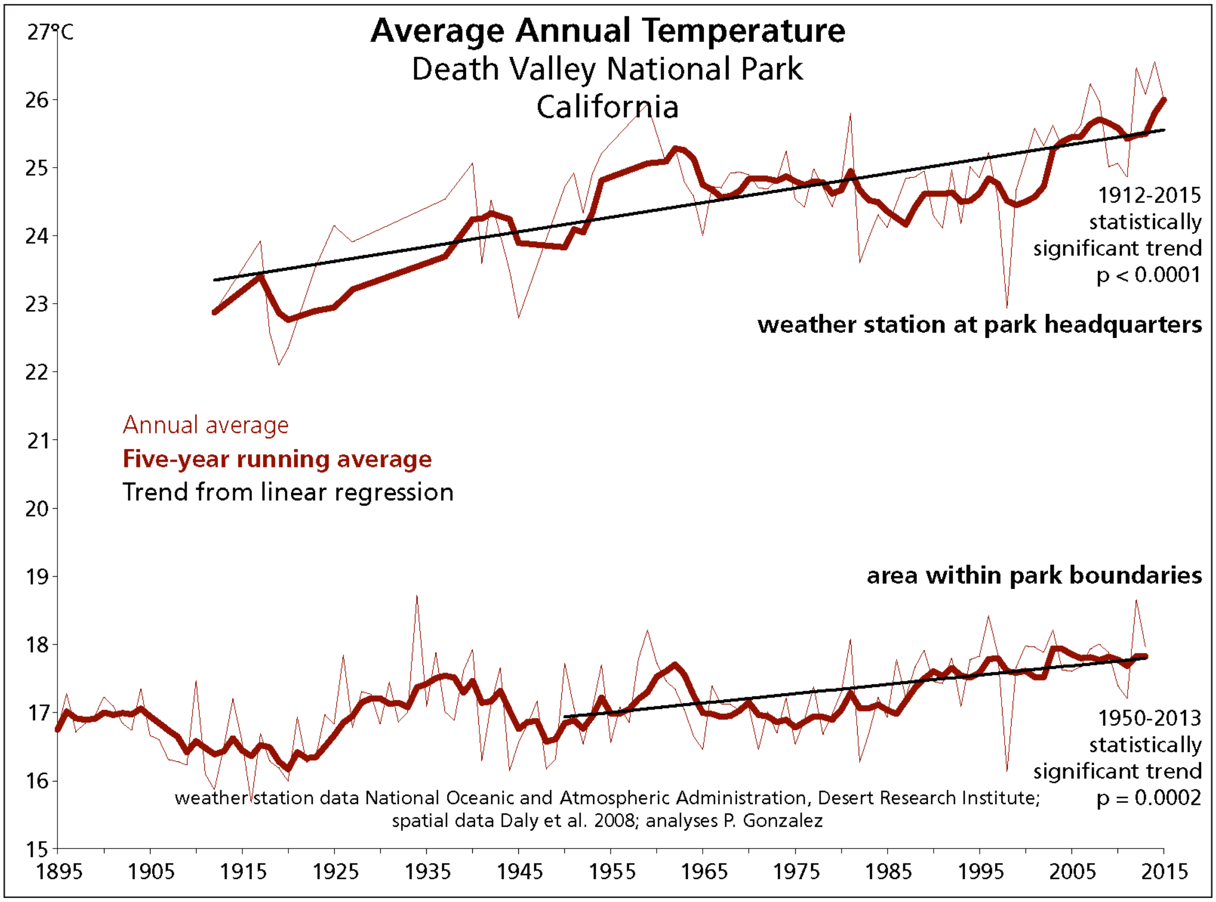
Ecosystem Carbon

- **Carbon density** Since the park does not have extensive areas of high-carbon ecosystems such as forest, the carbon density of the park as a whole in 2010 was 0.5 ± 0.5 tons per hectare (Gonzalez et al. 2015).
- **Carbon stock and change** Aboveground vegetation in Death Valley National Park contains 600 000 ± 700 000 tons of carbon (Figure 6), equivalent to the annual greenhouse gas emissions of 106 000 ± 125 000 Americans (Gonzalez et al. 2015). The highest carbon stocks are in the conifer woodlands of the Panamint Range. The carbon storage of the park decreased ~4% between 2001 and 2010, with some decreases in the area around Telescope Peak (Figure 7).

Table 1. Historical rates of change per century and projected future changes in annual average temperature and annual total precipitation for the park as a whole (data Daly et al. 2008, IPCC 2013; analysis Wang et al. in preparation). The table gives the historical rate of change per century calculated from data for the period 1950-2010. The U.S. weather station network was more stable for the period starting 1950 than for the period starting 1901. For the projections, note that under RCP6.0, temperature ramps up more slowly than under RCP4.5, but eventually overtakes the low scenario after mid-century. This is a property of how the emissions scenarios are written, with population and energy hitting their peak earlier, but at an eventually more sustainable level in RCP4.5. The table gives central values with standard errors (historical) and standard deviations (projected).

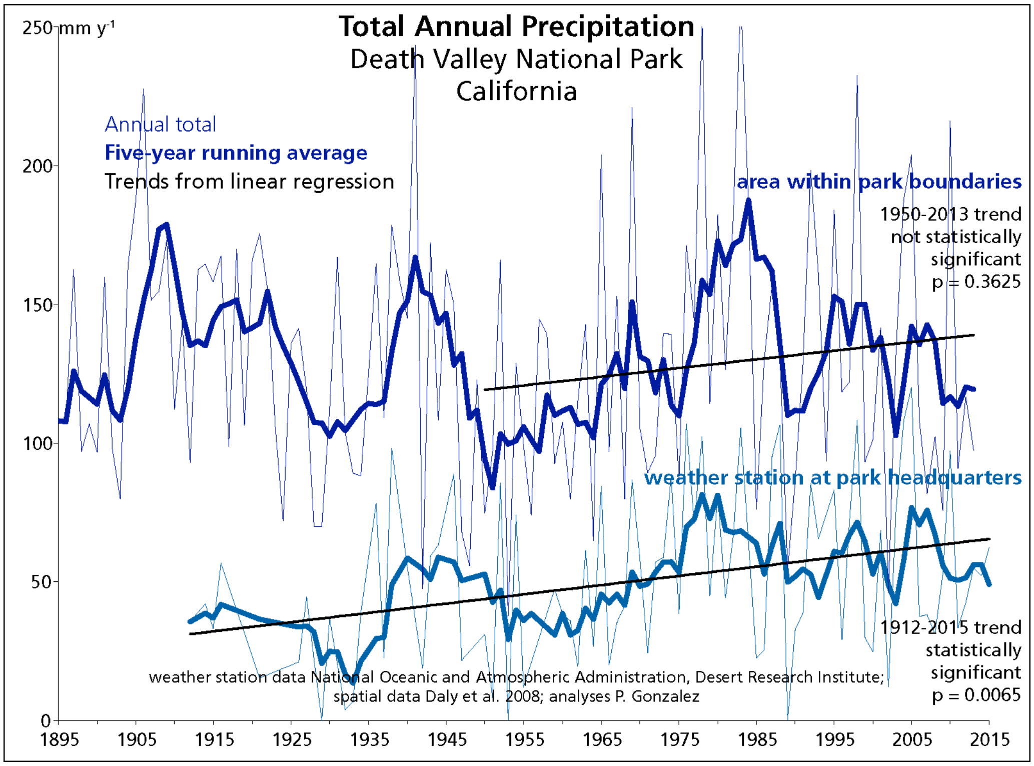
	1950-2010	**2000-2100**
Historical		
temperature	+1.3 ± 0.5°C per century (2.3 ± 0.9°F. per century)	
precipitation	+38 ± 27% per century	
Projected (compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature		+1.7 ± 0.7°C (+3.1 ± 1.3°F.)
precipitation		+9 ± 12%
Low emissions (IPCC RCP4.5)		
temperature		+2.8 ± 0.7°C (+5 ± 1.3°F.)
precipitation		+6 ± 11%
High emissions (IPCC RCP6.0)		
temperature		+3.2 ± 0.8°C (+5.8 ± 1.4°F.)
precipitation		+6 ± 13%
Highest emissions (IPCC RCP8.5)		
temperature		+4.9 ± 1°C (+8.8 ± 1.8°F.)
precipitation		+8 ± 19%

Figure 1



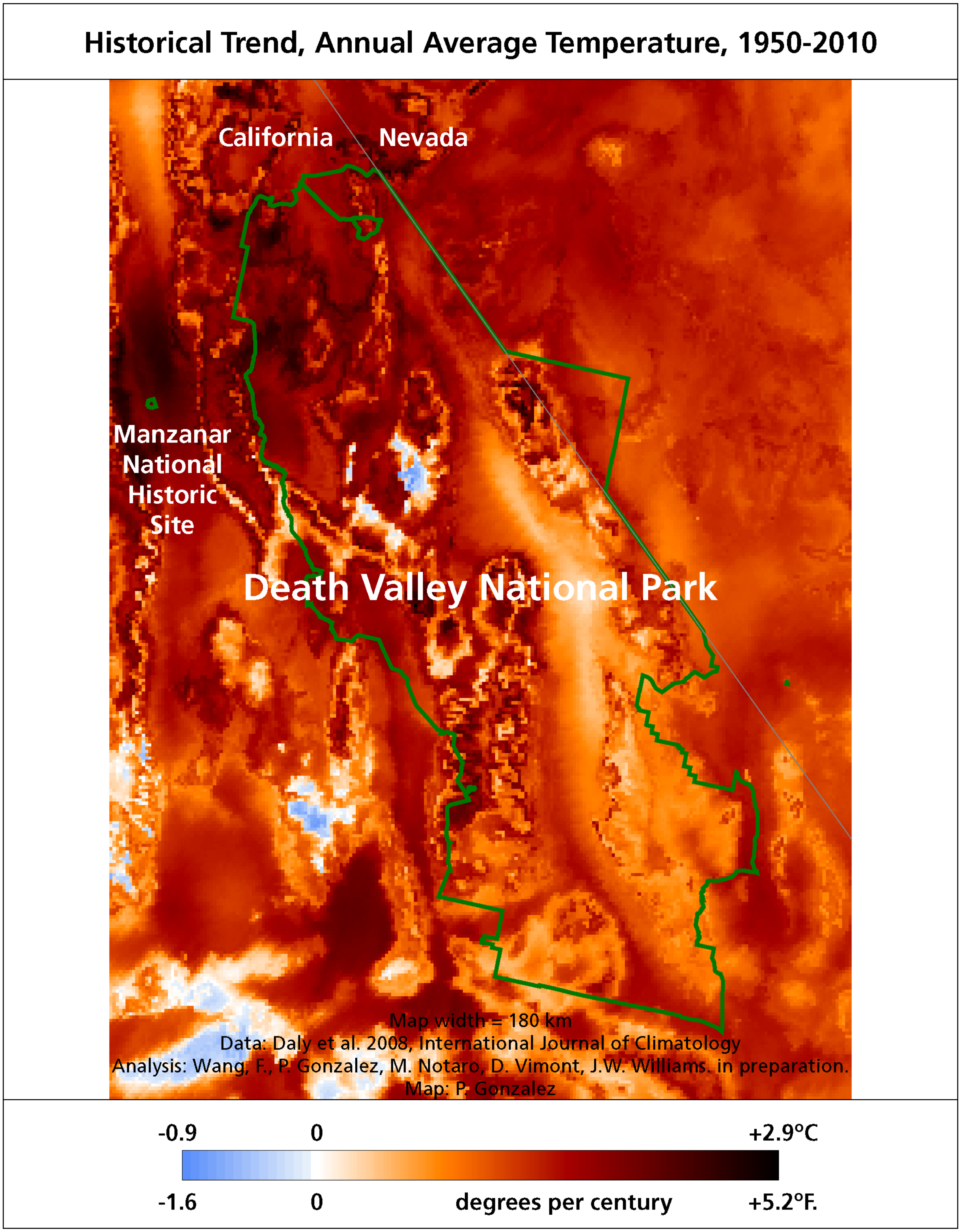
For the spatial data (bottom graph of the area within park boundaries), the period 1950-2013 gives a more robust time series than the period 1895-2013. The U.S. Government established a substantial number of weather stations in the late 1940s and the weather station network has been relatively stable since then. Spatial data from the longer period relies on fewer weather stations and a network that enlarged irregularly before the 1940s. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 2



For the spatial data (top graph of the area within park boundaries), the period 1950-2013 gives a more robust time series than the period 1895-2013. The U.S. Government established a substantial number of weather stations in the late 1940s and the weather station network has been relatively stable since then. Spatial data from the longer period relies on fewer weather stations and a network that enlarged irregularly before the 1940s. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 3



Historical Trend, Annual Average Temperature, 1950-2010
California
Nevada
Manzanar National Historic Site
Death Valley National Park
Map width = 180 km
Data: Daly et al. 2008, International Journal of Climatology
Analysis: Wang, F., P. Gonzalez, M. Notaro, D. Vimont, J.W. Williams. in preparation.
Map: P. Gonzalez
-0.9
0
+2.9°C
-1.6
0
degrees per century
+5.2°F.

Figure 4

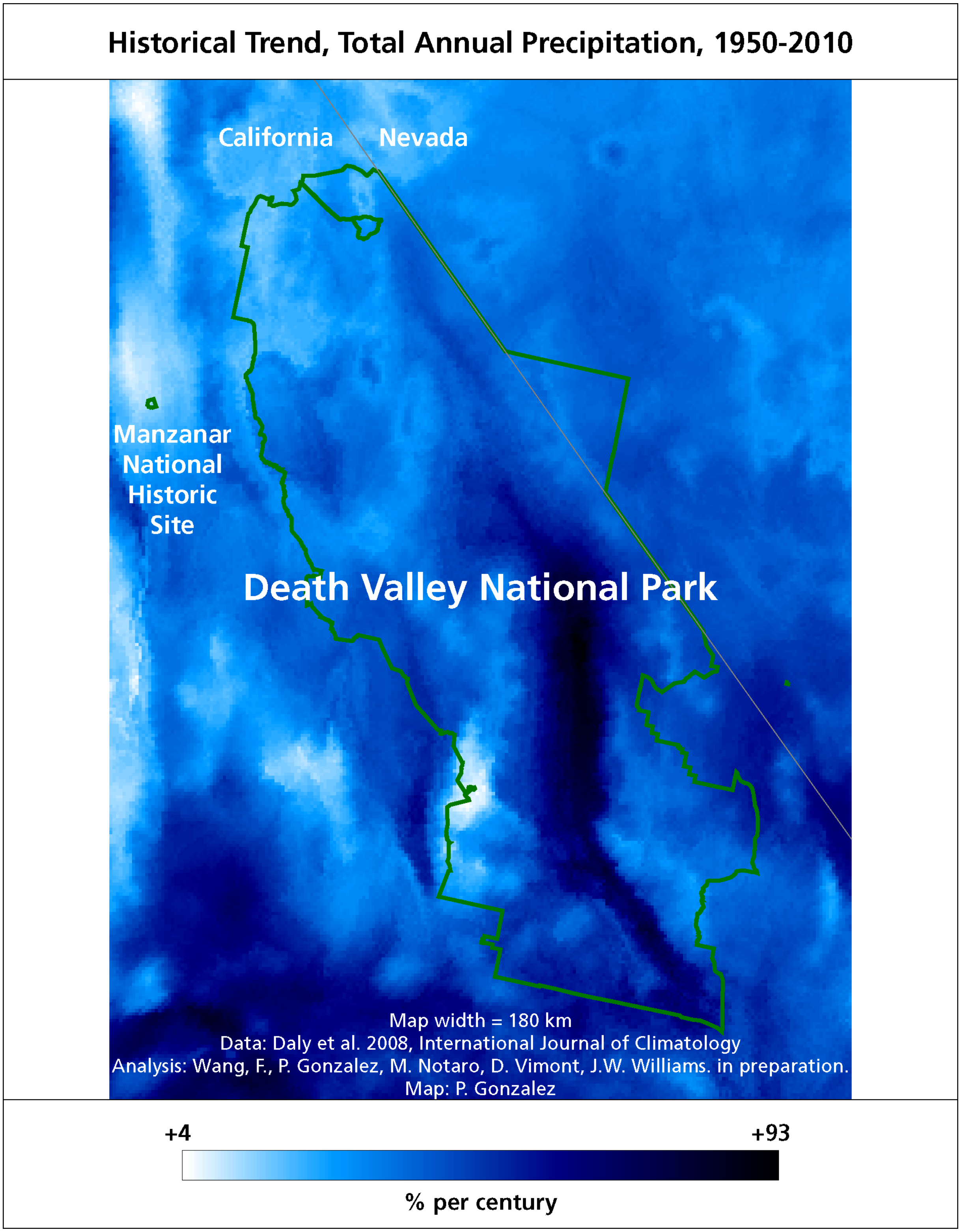

Historical Trend, Total Annual Precipitation, 1950-2010
California
Nevada
Manzanar National Historic Site
Death Valley National Park
Map width = 180 km
Data: Daly et al. 2008, International Journal of Climatology
Analysis: Wang, F., P. Gonzalez, M. Notaro, D. Vimont, J.W. Williams. in preparation.
Map: P. Gonzalez
+4
+93
% per century

Figure 5. Projections of future climate for the area within park boundaries, relative to 1971-2000 average values. Each small dot is the output of a single GCM. The large color dots are the average values for the four IPCC emissions scenarios. The lines are the standard deviations of each emissions scenario average. (Data: IPCC 2013, Daly et al. 2008; Analysis: F. Wang, P. Gonzalez, M. Notaro, D. Vimont, J.W. Williams).

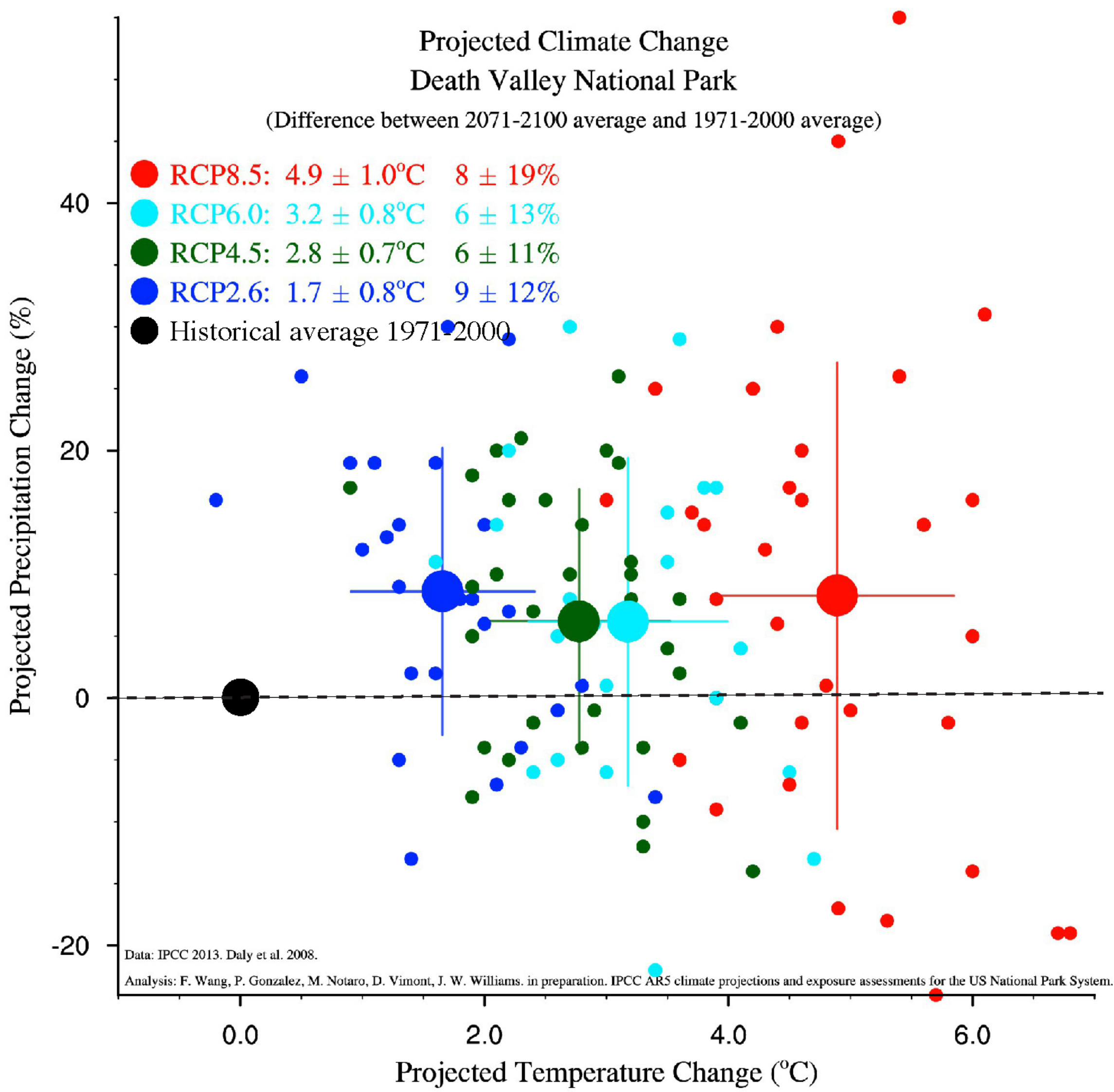
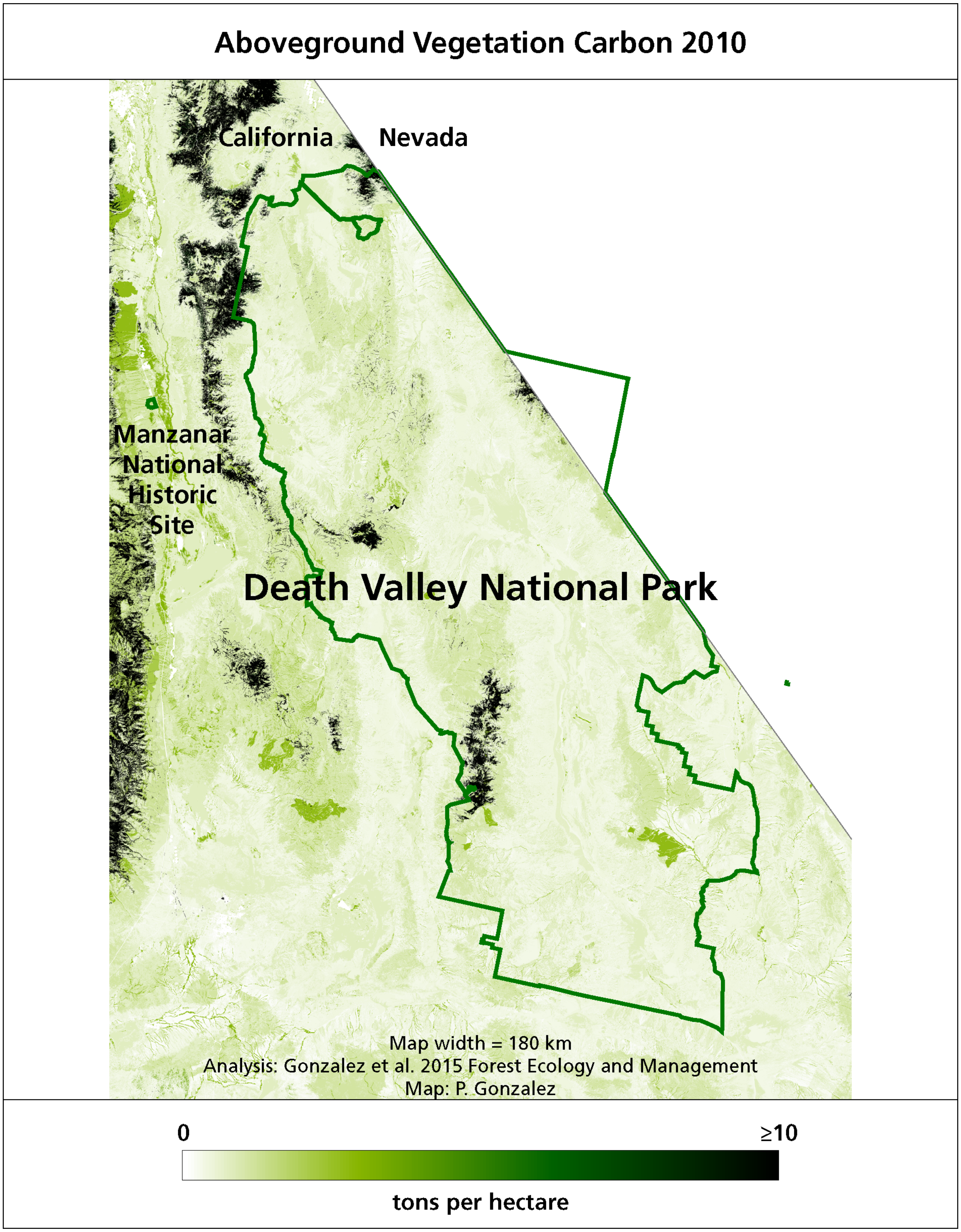
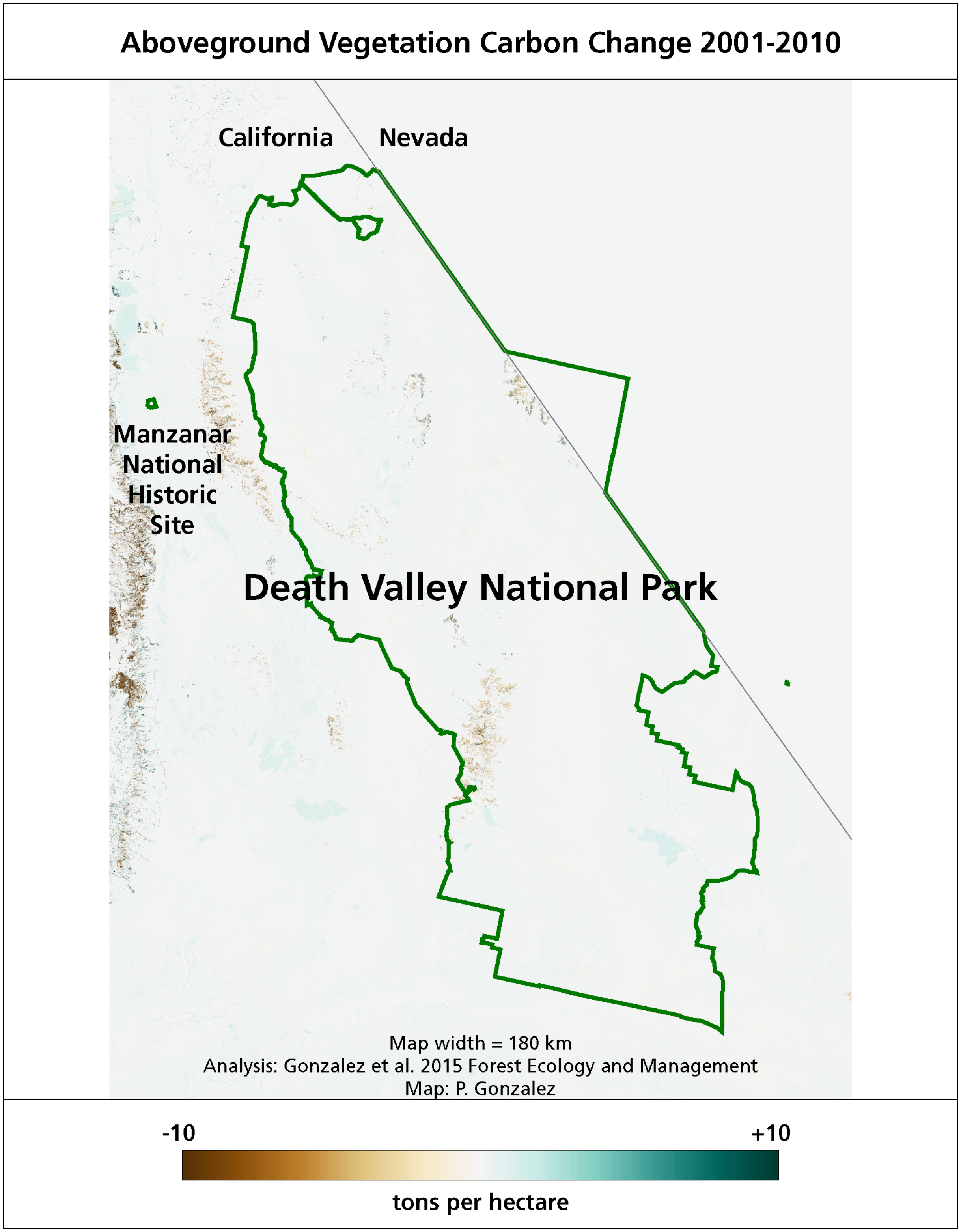


Figure 6



Aboveground Vegetation Carbon 2010
California
Nevada
Manzanar National Historic Site
Death Valley National Park
Map width = 180 km
Analysis: Gonzalez et al. 2015 Forest Ecology and Management
Map: P. Gonzalez
0
≥10
tons per hectare

Figure 7


Aboveground Vegetation Carbon Change 2001-2010
California
Nevada
Manzanar
National
Historic
Site
Death Valley National Park
Map width = 180 km
Analysis: Gonzalez et al. 2015 Forest Ecology and Management
Map: P. Gonzalez
-10
+10
tons per hectare

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